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G01J 1/42, B23K 26/00

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G1A AA1 AD10 AG17 AG7 AHS AP10 AP17 AP6 AP9 AR6 AR7 AS2 AS4 AT1 AT2
B3R RAC R138
U1S S1673 S1909

(56) Documents cited
GB 2241779 A GB 2155175 A GB 2151777 A
EP 0092753 A US 4567345 A

(58) Field of search
UK CL (Edition K) G1A AHP AHS, G3R RBQ59
INT CL⁵ G01J

(54) Monitoring laser material processing

(57) A method and apparatus for obtaining an indication of the quality of a laser material processing operation wherein at least two of the parameters comprising melt pool temperature, vapour intensity and plasma intensity are monitored separately but simultaneously. Sensors 10, 12 responsive to different parts of the electromagnetic spectrum associated with different ones of said parameters are arranged so as to receive radiated light from the vapour and plasma plume region 16.

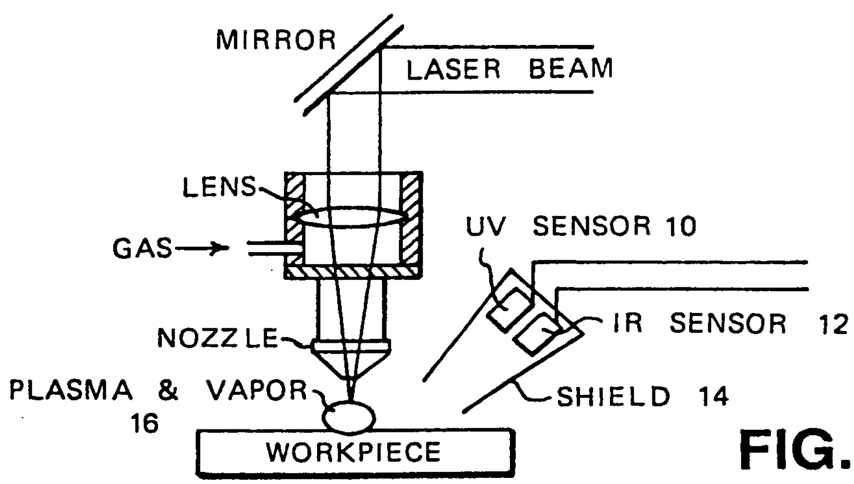


FIG. 1 a

GB 2 260 402 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

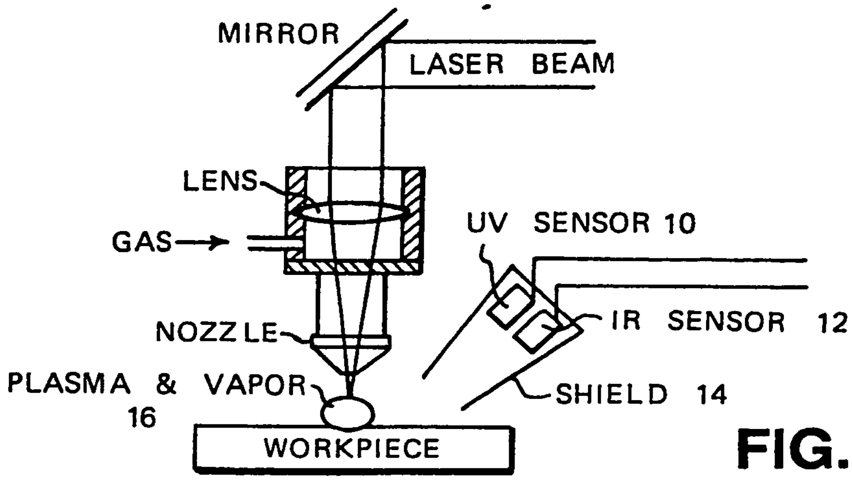


FIG. 1 a

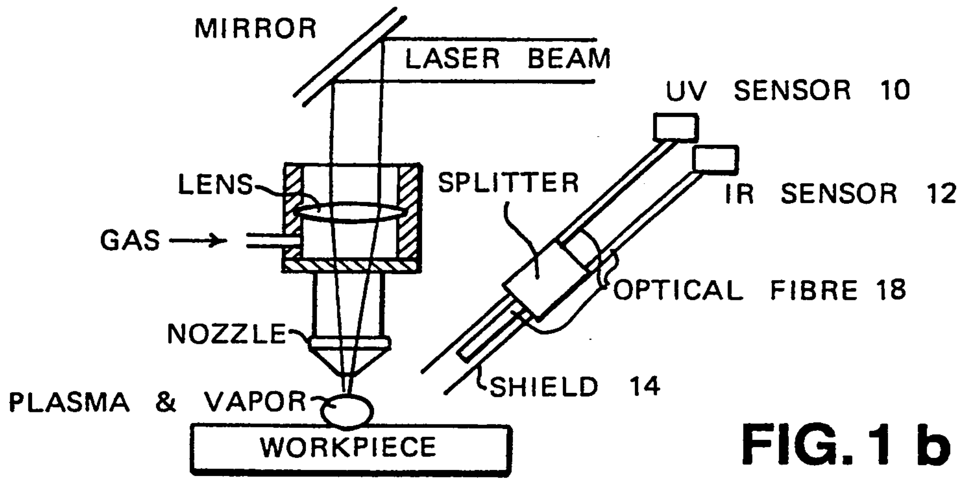


FIG. 1 b

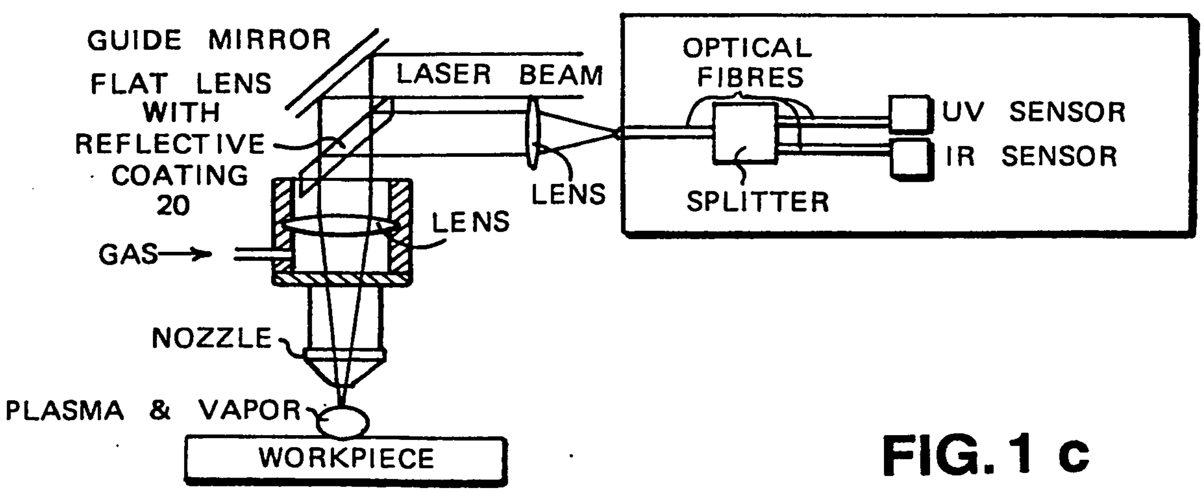
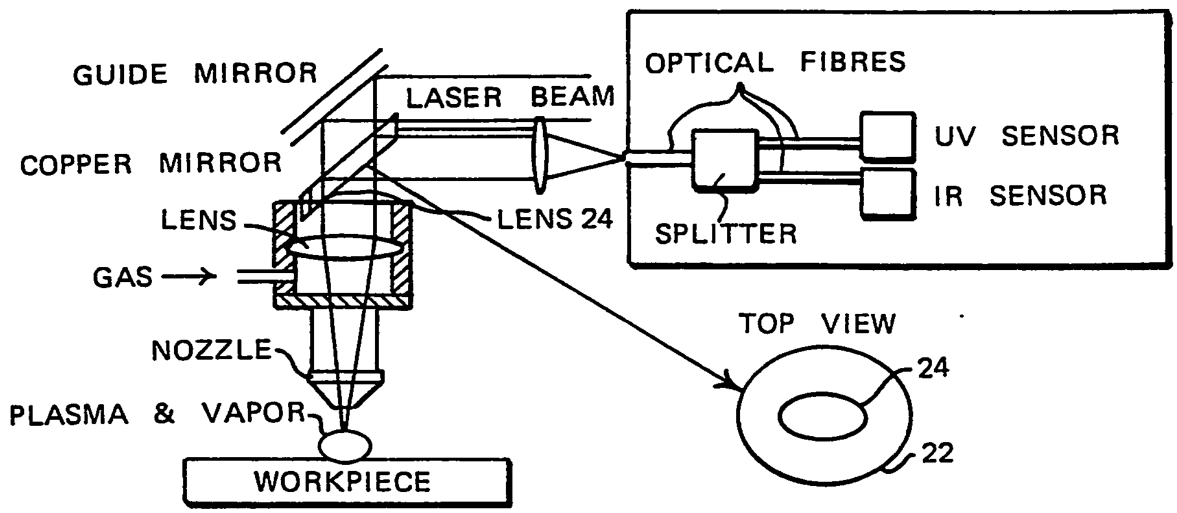


FIG. 1 c

FIG. 1d


GUIDE MIRROR
LASER BEAM
COPPER MIRROR
LENS
LENS 24
GAS
NOZZLE
PLASMA & VAPOR
WORKPIECE
OPTICAL FIBRES
UV SENSOR
IR SENSOR
SPLITTER
TOP VIEW
24
22

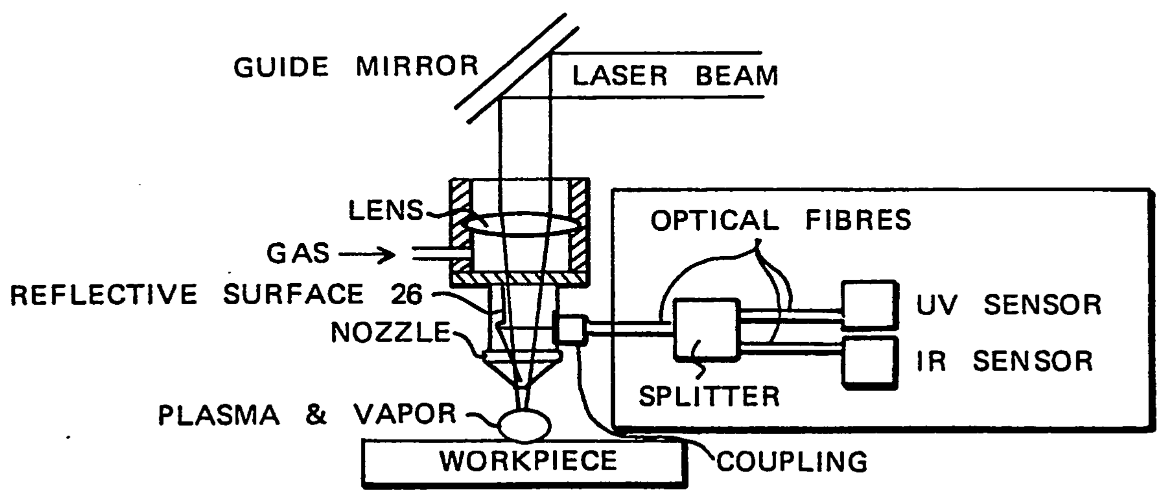

GUIDE MIRROR
LASER BEAM
LENS
GAS
REFLECTIVE SURFACE 26
NOZZLE
PLASMA & VAPOR
WORKPIECE
OPTICAL FIBRES
UV SENSOR
IR SENSOR
SPLITTER
COUPLING

FIG. 1e

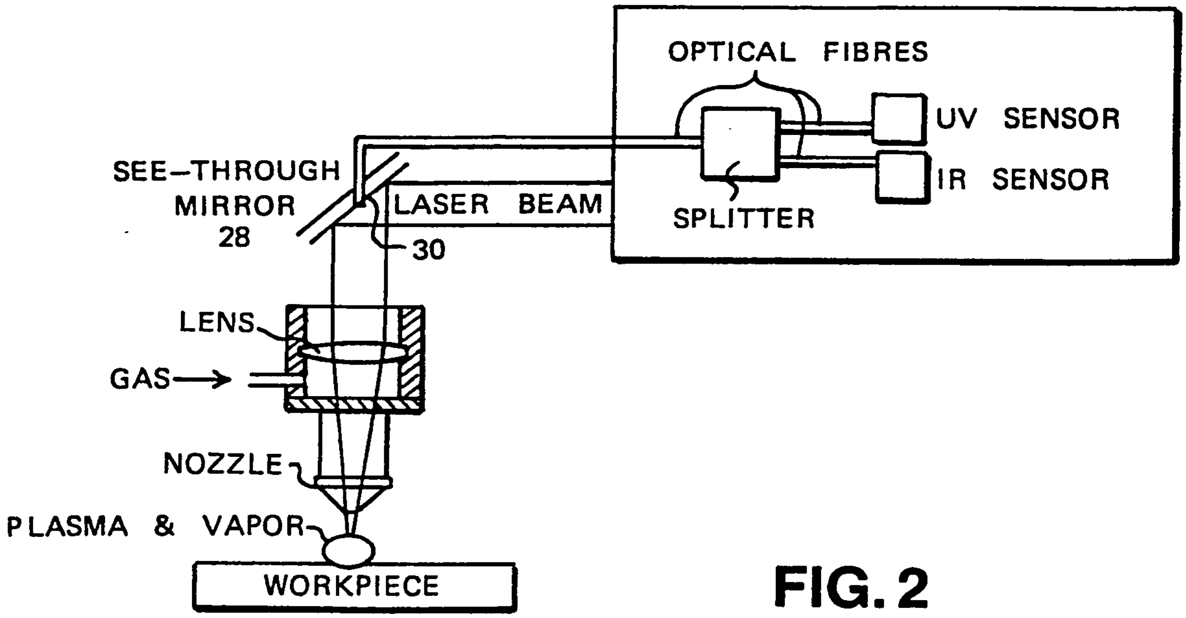

OPTICAL FIBRES
UV SENSOR
IR SENSOR
SPLITTER
SEE-THROUGH MIRROR 28
LASER BEAM
30
LENS
GAS
NOZZLE
PLASMA & VAPOR
WORKPIECE

FIG. 2

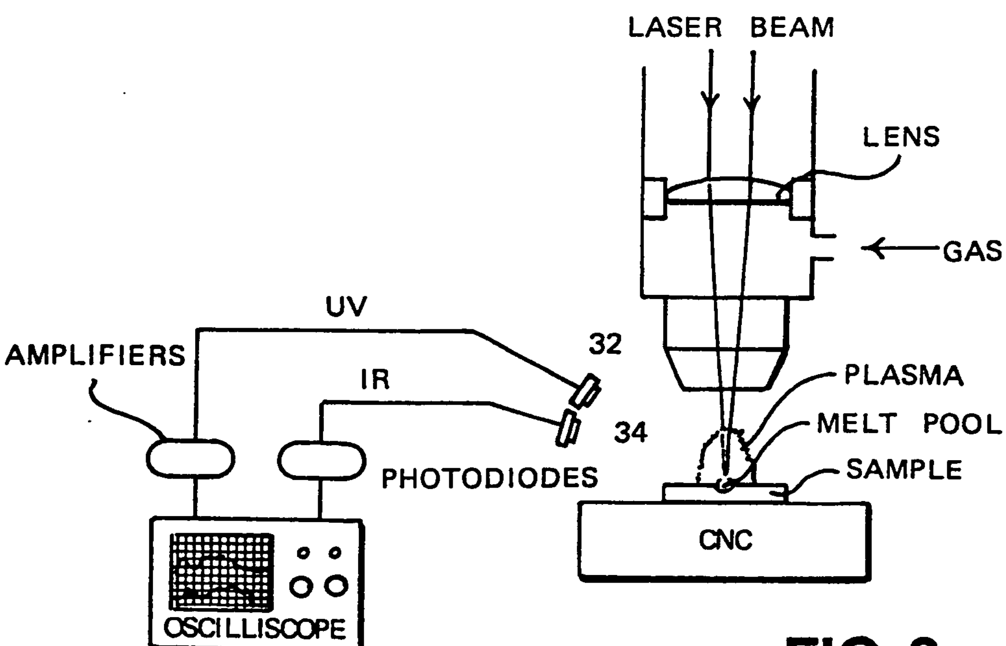
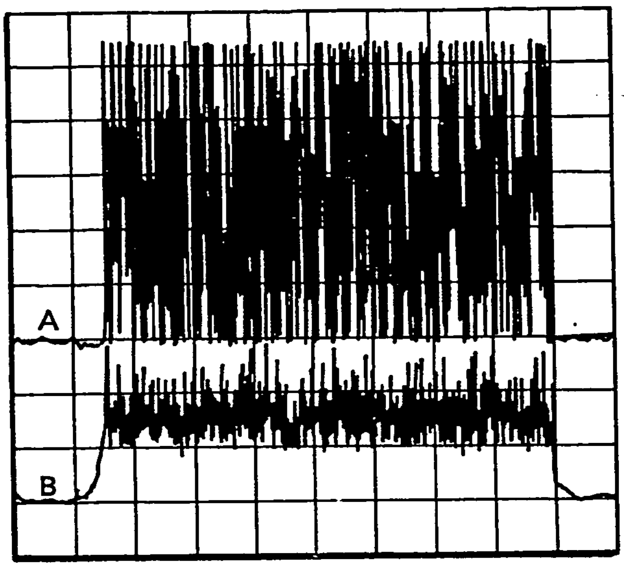

LASER BEAM
LENS
GAS
UV
32
AMPLIFIERS
IR
34
PLASMA
MELT POOL
SAMPLE
PHOTODIODES
CNC
OSCILLISCOPE

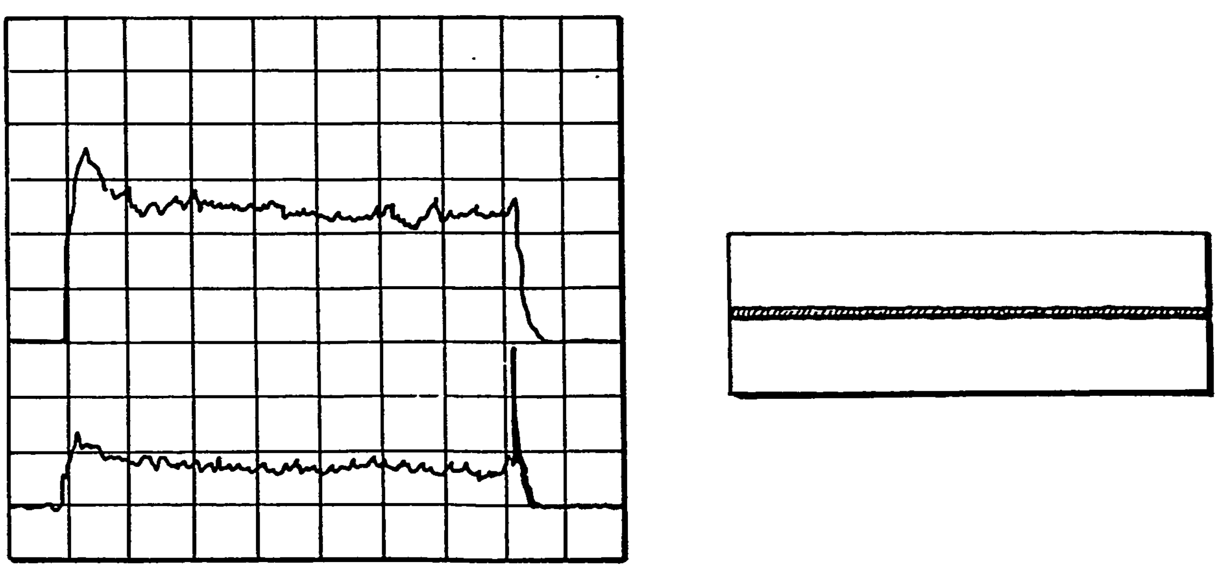
FIG. 3



REGO A: 1V + Omv T: 100 ms SNG DC
B: 200mv + OmV D: –10 IV/A

FIG. 4 a

FIG. 4 b



REGO A: 1V + OmV T: 1oo 100ms SNG DC
B: 500 mv = + Omv D; – 1DIV/A

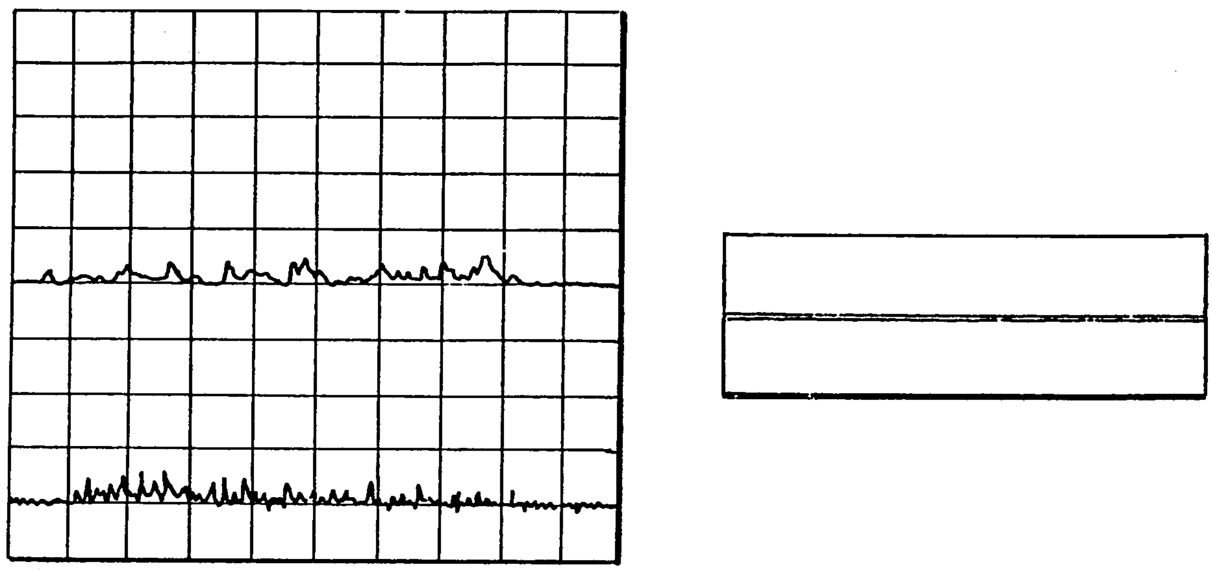


FIG. 5a

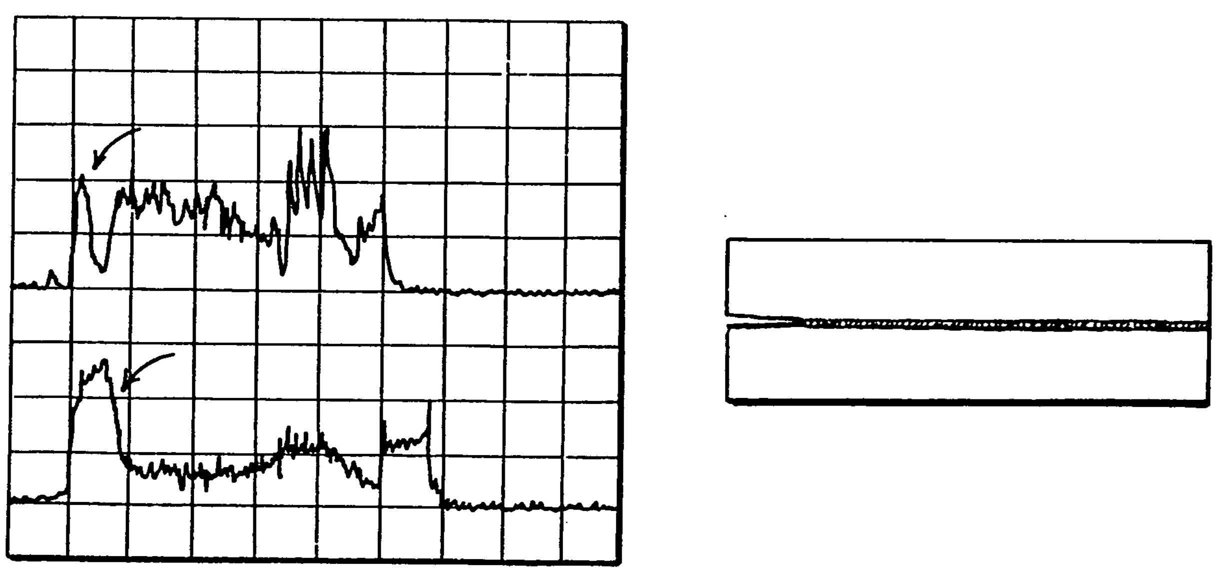
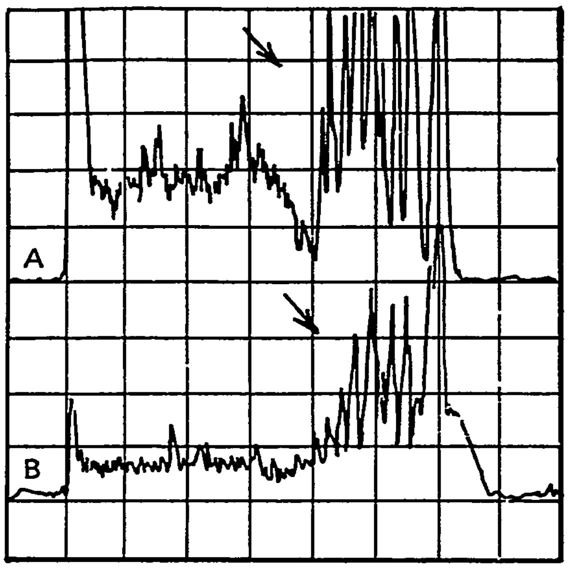


FIG. 5b

A CUT AT THE START



REGO A: 100mV + OmV T: 200ms SNG DC
B: 100mV + OmV D: — 1DIV/A

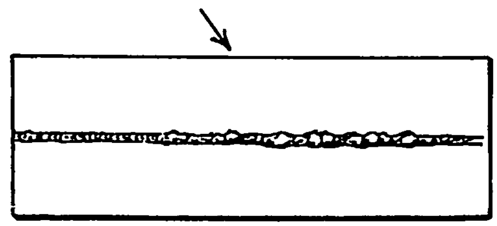
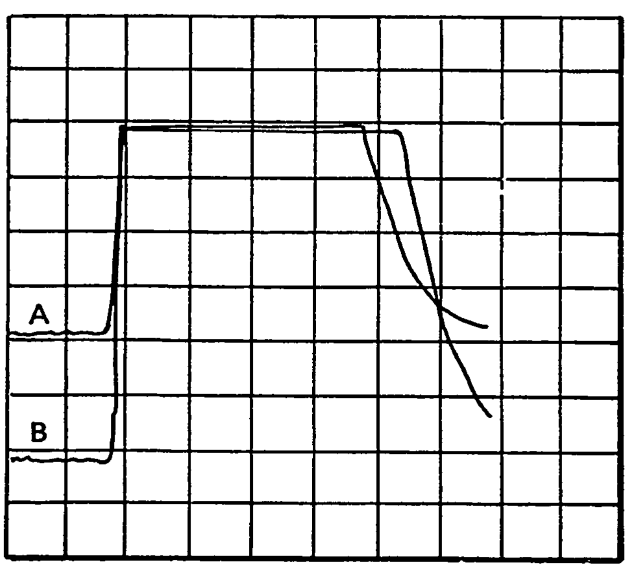


FIG. 5c



REGO A: 200mV + OmV T: 500ms SNG AUTO
B: 200mV + = OmV D: + O DIV/ S

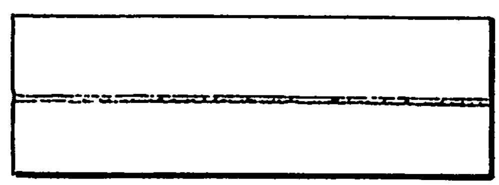
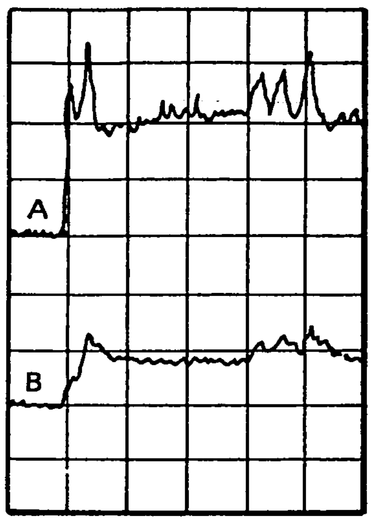


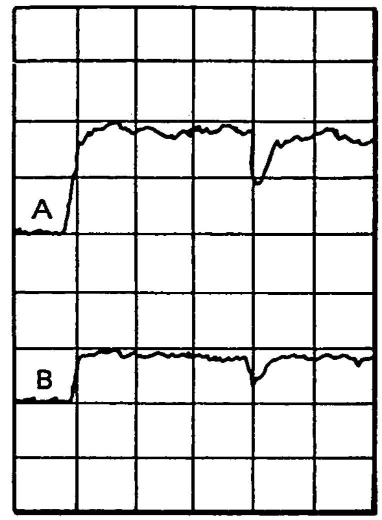
FIG. 5d

POOR WELD. NO PENETRATION



REGO A: 50imV + 0mV T
B: 500mV + 0mV O

FIG. 6a



REGO A: 1V + 0mV T
B; 500mV + 0mV C

FIG. 6b

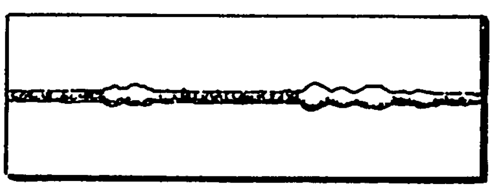


FIG. 6c

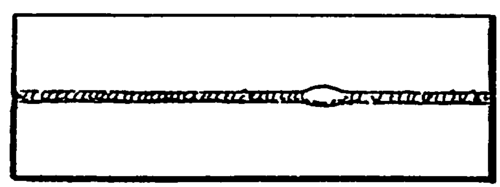


FIG. 6d

DESCRIPTION

APPARATUS AND METHOD FOR MONITORING LASER MATERIAL PROCESSING

The present invention relates to an apparatus and method for monitoring laser material processing.

The advantages of laser welding over the conventional welding processes in terms of flexibility, speed and weld quality are now well recognised. Indeed many applications of lasers to welding in industry have already been accepted. As more welding systems are being installed by industry, the demand increases for the development of in-process techniques to monitor and control the process quality. This is necessary since weld quality is often affected by the instability of plasma formation during laser welding and instabilities of laser power density.

During laser materials processing, such as laser welding, the workpiece surface is heated by the laser radiation to above its melting point, with some of the material being vapourised. Upon further radiation by the laser beam, the material vapour, together with the surrounding gases, are ionized by the intensive heating from the laser beam, thereby forming a plasma plume in and above the melt pool. Enhanced beam absorption can be achieved through interaction of the

plasma with the laser beam and energy transfer from the plasma workpiece. However, if the plasma density is too high, the beam absorption will be reduced. Since the plasma is expanding rapidly, the beam absorption is not a constant. This causes variation in weld quality during processing. Also, when the operating parameters of the process are not kept stable or there is a fault on the workpiece, the weld quality can also be affected.

It has been found by the present inventors that melt pool temperature, vapour radiation intensity and plasma radiation intensity are three principal factors which reflect the process quality. However, monitoring only one of the latter parameters or the continued effect of any two of them is found to be insufficient for reliable process quality diagnosis.

In accordance with a first aspect of the present invention, there is provided a method of obtaining an indication of the quality of a laser material processing operation, wherein at least two of the parameters comprising melt pool temperature, vapour radiation intensity and plasma radiation intensity, are monitored separately but simultaneously.

In accordance with a second aspect of the present invention, there is provided an apparatus for providing an indication of the quality of a laser

material processing operation, comprising means for separately but simultaneously monitoring at least two of the parameters comprising melt pool temperature, vapour radiation intensity and plasma radiation intensity.

In one embodiment, since the molten material, vapour and plasma radiate light or electromagnetic waves at different wavelengths, the aforementioned three parameters can be monitored by the detection simultaneously of the light radiation emitted by them separately so that the state of melt pool and key-hole can be monitored, which are directly related to the welding quality.

In other embodiments, the above-identified light radiations can be detected using photo-electric sensors with different response spectra corresponding to the principal radiation spectrum of two or three of the above parameters separately, or optical sensors which can identify the different light radiations.

Still further embodiments can use broad band optical sensors with optical filters at different spectra corresponding to the relative light spectrum. An optical shield can be used to reduce the effect of other light sources.

A further embodiment of the sensor arrangement can utilize optical beam splitters which can separate different optical radiation sources. The beam

splitters can be placed between the laser generator and the workpiece and the light which has been split can be forwarded to the optical sensors.

A further embodiment of the sensor arrangement can utilize a lens or mirror reflector placed between the laser generator and the workpiece to direct the radiated light waves to the sensor.

In a further embodiment of the sensor arrangement, optical fibres with a cut off spectrum for the laser beam wavelength can be used, either as a bundle or bifurcated or tri-furcated form, placed in the space between the laser generator and the workpiece for the collection of optical signals. The other ends of the optical fibre are connected to the photo-electric sensors so that the temperature of the sensor cannot be affected by the heat radiation from the melt pool or scattered laser beam. An optical shield can be used to protect the fibres and prevent the influence of unwanted light sources.

Some of the above mentioned apparatuses can be made in the form of a cylindrical optical probe with protective covers and windows.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings, in which:-

Figs.1a to 1e illustrate several ways of

detecting different optical radiation sources from or near the laser generated melt pool.

Fig.1a illustrates a basic form of the device where two optical sensors 10,12 with different response spectra, say UV and IR, are placed in a metal shield tube 14 with or without a front window. The sensors 10,12 look directly at the vapour and plasma plume 16 at a distance from them. The distance can be as far as two feet depending on the sensitivity of the sensors 10,12.

Fig.1b illustrates the use of a bifurcated optical fibre 18 with one input and two outputs for the sensory unit. The input end of the optical fibre is facing the melt pool at a distance from it and the other two connected to the optical sensors 10,12. Again an optical shield 14 can be used to prevent the influences of the unwanted light.

Fig.1c shows the uses of a flat lens 20 which can transmit the laser beam but reflect the visible light. The light radiation from the vapour, plasma and melt pool can therefore be focused and collected using either the optical fibre system of Fig.1(b) or the basic form of Fig.1(a).

Fig.1d uses a reflective mirror 22 with a hole 24 in the middle to let the laser beam pass. The mirror 22 is about 45° or other angle to the laser beam axis

and will then reflect some of the light from the vapour and plasma plume to the fibre optic sensory unit of Fig.1(b) or the basic sensory unit of Fig.1(a) through a lens collector 24. If the mirror is curved to focus the collected light, the additional lens 24 is not necessary.

Fig.1e illustrates the collection of light radiation by the vapour and plasma plume or melt pool temperature radiation through an angled surface 26 in the nozzle. The optical fibre system is then connected to the nozzle through a coupling.

Fig.2 illustrates the combination of the present invention with a known "see-through mirror 28, having a hole 30 in the middle of the mirror" for the monitoring of laser processing quality coaxial to the laser beam.

Fig.3 illustrates a sensing arrangement for a welding monitoring experiment with two different sensors 32,34 (near IR and UV light sensors) looking down to the melt pool region during laser welding since, during laser welding of steel plates with an inert gas such Ar as the shroud gas, the plasma light is usually in the blue spectrum and the radiation of the vapour of melt pool is in the red spectrum. In these experiments a signal smoothing circuit was used to reduce the fluctuating level of the signal.

Fig.4 shows the differences between the smoothed and the un-smoothed signals.

Fig.5a shows the sensor responses to a weld where there is lack of penetration (A:UV, B:IR);

Fig.5b shows the sensor responses to a weld which has irregular hole cutting (A:UV, B:IR);

Fig.5c shows the sensor responses to a weld which is over powered with craters on the surface (A:UV, B:IR);

Fig.5d shows the sensor response to a weld which generates a glare type plasma where most of the energy was carried away (A:UV, B:IR).

The following rules have been established:

a) When IR sensor response is smooth and low and UV sensor response is smooth and high, the laser weld is good (Fig.5b);

b) When both IR and UV sensor responses are low, the laser weld has a lack of penetration or loss of key hole (special case of poor penetration because the laser beam is reflected too much) (Fig.5a);

c) When IR sensor response is high and UV sensor response is low there is either a cut or the laser beam is slightly out of focus (little plasma is generated) (Fig.5b);

d) When both IR and UV sensor responses are high and oscillating the weld is over-powered, generating

vapour craters on the weld surface (Fig.5c);

e) When both sensor responses are high and not oscillating, there will be a glare type of plasma radiation. No weld is generated (Fig.5d);

f) For thinner plate welding the levels of signal responses are lower than those of thicker plates. However, the general diagnostic rules listed above still hold.

g) Other types of weld faults (Figs.6a to 6d) can also be identified by the sensor arrangement.

It can be seen from the above examples that monitoring only one type of light radiation (either IR or UV or a mixture) can not give a definite conclusion for weld diagnosis. For example, when the plasma light sensor is low it can be for one of two possibilities; low penetration (or loss of key hole) or a cut. However, if at the same time the vapour-molten material radiation sensor is low, then it is definitely as a result of a low penetration (or loss of key hole if plasma sensor response is zero). Otherwise it will be a cut. Therefore the logical combination of the two types of light radiation monitoring separately at the same time can give a reliable diagnosis.

CLAIMS

1. A method of obtaining an indication of the quality of a laser material processing operation, wherein at least two of the parameters comprising melt pool temperature, vapour radiation intensity and plasma radiation intensity, are monitored separately but simultaneously.

2. A method as claimed in claim 1, wherein said parameters are monitored by separately and simultaneously detecting the light radiation at wavelengths associated with those parameters.

3. An apparatus for providing an indication of the quality of a laser material processing operation, comprising means for separately but simultaneously monitoring at least two of the parameters comprising melt pool temperature, vapour radiation intensity and plasma radiation intensity.

4. Apparatus as claimed in claim 3, comprising sensor means responsive to different parts of the electromagnetic spectrum associated with different ones of said parameters and arranged to be placed so as to receive radiation from the laser processing region.

5. Apparatus as claimed in claim 4, wherein one said sensor means is responsive to UV and another is responsive to IR.

6. Apparatus as claimed in claim 4, comprising photo-electric sensors having different response spectra corresponding respectively to the principal radiation spectra of said parameters.

7. Apparatus as claimed in claim 4, comprising broad band optical sensors having optical filters with different transmission or reflection spectra corresponding to spectrum bands associated with the parameters to be monitored.

8. Apparatus as claimed in claim 4, comprising an optical beam splitter adapted to separate optical radiation sources of different spectral signature and positioned between the laser source and a workpiece, the light components separated by said beam splitter being passed to respective optical sensors.

9. Apparatus as claimed in claim 4 or 5, comprising a lens or mirror reflector positioned between the laser source and the workpiece for directing the radiated light to said sensor means.

10. Apparatus as claimed in claim 4, comprising one or more optical fibres whose one end or ends are positioned in the space between the laser source and the workpiece for the collection of said radiation and leading same to said sensor means.

11. Apparatus as claimed in claim 4 or 10, including a radiation shield for protecting the

radiation sensors and/or optical fibre or fibres.

12. A method of obtaining an indication of the quality of a laser material processing operation, substantially as hereinbefore described, with reference to the accompanying drawings.

13. An apparatus for providing an indication of the quality of a laser material processing operation, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

Patents Act 1977
.xaminer's report to the Comptroller under Section 17 (The Se[redacted]h Report)

Application number

9[redacted]3315.2

Relevant Technical fields

(i) UK Cl (Edition K) G1A AH5,AHP; G3R RBQ59

(ii) Int Cl (Edition 5) G01J

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner

A J OLDERSHAW

Date of Search

10 DECEMBER 1991

Documents considered relevant following a search in respect of claims ALL

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
Y,E	GB 2241779 A (GEC) see page 10 lines 15-18, lines 23-24; page 14 lines 20-25	1-4,7,9, 10
Y	GB 2155175 A (CENTRO) see page 1 lines 63-70, lines 116-119; page 2 lines 36-52	1-4, 7,10
Y	GB 2151777 A (GUSTAV) see page 1 lines 56-62, lines 92-96; page 3 lines 101-112	1-4,6,10
Y	EP 0092753 (GEC) see page 4, lines 18-21	1-4,10
X	US 4567345 (BACHET) see column 3 lines 37-50; column 4 lines 63-68	1-4,7, 9,10

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

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